Power-Friendly Access Network Selection Strategy for Heterogeneous Wireless Multimedia Networks

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***Abstract* — Apart from the number and types of applications available to users of diverse devices with various characteristics, a highly relevant issue in current and future wireless environment is the coexistence of multiple networks supported by various access technologies deployed by different operators. In this context, the aim is to keep the mobile users "always best connected" anywhere and anytime in such a multi-technology multi-application multi-terminal multi-user environment. Multimedia streaming to battery powered mobile devices has become widespread. However, the battery power capability has not kept up with the advances in other technologies and it is rapidly becoming a concern. Since multimedia applications are known to be high energy consumers and since the battery lifetime is an important factor for mobile users, this paper proposes a network selection algorithm which bases its decision on the estimated energy consumption. The proposed solution enables the multimedia stream to last longer while maintaining an acceptable user perceived quality by selecting the least power consuming network.**

***Index Terms* — real-time applications, wireless networks, network selection**

I. Introduction

GETTING online anytime and anywhere has become a necessity for many mobile users, especially with the popularity of the social networking sites such as: MySpace, Facebook, Linkedin, etc. Even if they are used only for business (e.g., to post a profile, or look for a job), to connect to people (e.g., share videos, music, photos) or share social media (e.g., news, personal experience, reviews), they have become a part of the daily life when on the move or stationary (e.g., at home/office/airport/coffee bars, etc.). It is known that real-time applications, and in particular those which based on multimedia, have strict Quality of Service (QoS) requirements, but they are also the most power-consuming. In this context one of the impediments of progress is the battery lifetime of the mobile device. With advances in technology, the mobile user has now a wide choice of high capability mobile devices, from laptop computers and netbooks to Personal Digital Assistants (PDA) and smart phones. However the batteries have not evolved as much as processors and memory, and their capability is very much limited.

Figure 1. Example scenario: roaming user travelling across different access networks

Energy conservation has become a critical subject around the world. Information and Communications Technologies (ICT) are seen as part of the solution (e.g., video-conferencing) in order to avoid large travel footprints, but ICT itself needs to become more energy efficient. For example the EU Commission is pushing for ICT to reduce its own carbon footprint by 20% by 2015[1].

The deficiency in battery power and the need for reduced energy consumption provides motivation for development of a more energy efficient network selection mechanism.

In this paper we propose a novel power-friendly access network selection strategy which will select the least power consuming network (see Figure 1) in order to avoid the mobile device running out of battery in the middle of an important event (e.g., video conference, video streaming, voice call or any other real time application), but at the same time maintaining good user perceived quality levels.

The rest of the paper is structured as follows: section II summarizes the related work and section III describes the proposed network selection mechanism. Section IV details the performance evaluation and results. Finally, concluding remarks and future work details are given in section V.

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II. Related Works

One of the first researchers who approached the area of network selection strategy for heterogeneous wireless networks were Wang et al. in 1999. In [1] they described a policy-enabled network selection function. They define the cost of using a network as a function of bandwidth, power consumption, and price. Their function is the sum of a weighted normalized form of these three parameters. The network with the lowest value for the cost function is chosen as the target network. This cost function can be formally classified as a Simple Additive Weighted (SAW) method.

Since 1999 other papers offering variations of the SAW method, have been published [2]. In order to scale different characteristics of different units to a comparable numerical representation, different normalized functions were used, such as exponential, logarithmic, and linear piecewise functions [3]. Other classical multiple attribute decision-making (MADM) methods have also been used in order to find a solution to the network selection problem. These methods include: TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) [4], GRA (Grey Relational Analysis) and AHP (Analytic Hierarchy Process) [5]. The decision optimisation technique needs to have low computational complexity. On a battery-powered device it is important to keep the processing to a minimum, and not to impact the processor time devoted to the application. Also, long network selection duration will impact the handover latency. In [6] Mahmud et al. proposed an energy-aware model for the prediction of energy consumption in a wireless multi-mode terminal by investigating the power consumption pattern of the wireless interfaces.

Unlike previous works, this paper proposes a multiplicative weighted network selection utility function which uses an estimated energy consumption equation for real-time applications [6] in order to select the best energy efficient network.

III. Network Selection Mechanism

A. Proposed Architecture Stack

The IEEE 802.21 Media Independent Handover Working Group makes progress towards a standard in order to optimize the handover between heterogeneous networks [7]. However IEEE 802.21 only facilitates handover and does not specify the network selection algorithm, which is a major part of the handover process.

This paper addresses the problem of selecting the best network that satisfies user interests and an extended 802.21 reference model is proposed as in Figure 2. Figure 2 shows different components and their location across the network stack layers, including the *Network Selection* mechanism. For example, a video application which uses the proposed power friendly network selection mechanism can employ a transport layer protocol such as SCTP, a network layer protocol such as Mobile IP, the layer 2.5 802.21 MIH function and regular MAC and PHY layer protocols for delivery.

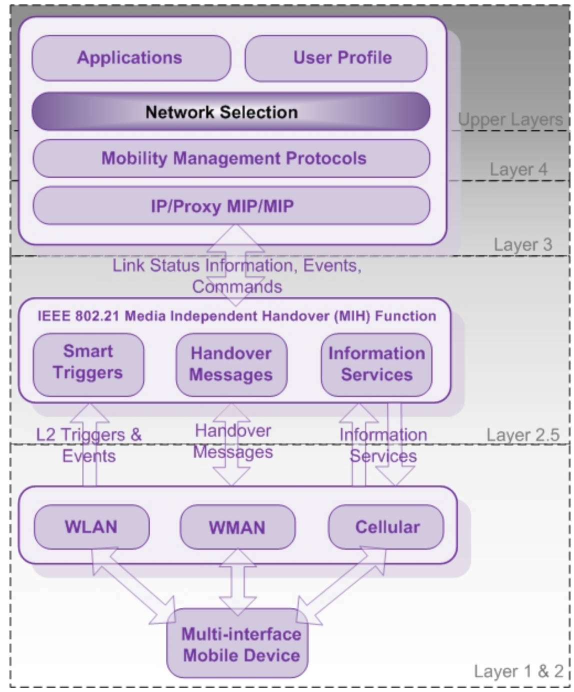

Figure 2. Proposed 802.21-based Network Selection Architecture Stack

B. Functional Principle

The proposed network selection algorithm takes into consideration the energy consumption of the mobile device when running real-time applications. Along with the estimated energy consumption, we also consider the monetary cost of the network, user mobility, application requirements, and estimated network conditions in terms of average throughput. Figure 3 illustrates the functional block diagram of the proposed mechanism.

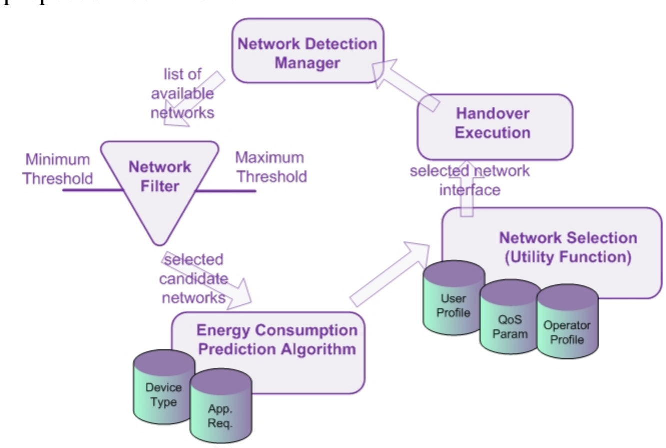

Figure 3. Functional Blocks of the Network Selection Mechanisms

The role of the *Network Detection Manager* is to scan the surrounding area and provide a list with the available networks to the *Network Filter*. *Network Filter* module will then eliminate the networks which do not meet minimum criteria. A basic minimum/maximum threshold is defined for each criteria and for each application type. In this way a first elimination of the available networks is made, and only the networks that pass these thresholds will be considered as candidate access networks for the network selection algorithm, much reducing the decision time. The energy consumption for the running application is then predicted for each of the selected candidate networks [6]. These estimated energy consumptions are used in evaluating the network selection utility function. The network with the highest score is selected as the target network. Knowing the target network, the *Handover Execution* module will trigger the handover mechanism and the mobile user will be fully served by the new network. Next section details the proposed utility function.

C. Proposed Network Selection Utility Function

The overall multiplicative multi-criteria utility function is given in equation (1):

$$U^i = (u_e^i)^{w_e} * (u_q^i)^{w_q} * (u_c^i)^{w_c} * (u_m^i)^{w_m}. \tag{1}$$

where: i – the candidate network, U – overall utility for network i and u_e, u_q, u_c, and u_m are the utility functions defined for energy, quality, monetary cost and user mobility for network i. Also it is known that $w_e + w_q + w_c + w_m = 1$, where w_e, w_q, w_c, w_m are the weights for the four considered criteria.

As mentioned, the overall utility function is computed for each of the selected candidate networks and the network with the highest score is selected as target network.

a) Energy Utility - u_e

The estimated energy consumption for a real time application is computed using equation (2) [6].

$$E = t(r_t + Th_{req} r_d) + c. \tag{2}$$

where: t – transaction time (sec), r_t - the mobile device's energy consumption per unit of time (W), Th_{req} – required throughput (kbps), r_d – energy consumption rate for data/received stream (Joule/Kbyte), ***c*** – constant, E – total energy consumed (Joule).

Usually the duration of the video streaming is known, so the transaction time can be easily predicted. The parameters r_d and r_t can be determined by running different simulations for various amounts of data and defining a power consumption pattern for each interface.

Having the estimated energy consumption, *E*, we define u_e' as in equation (3):

$$u_e' = \begin{cases} 0 & , \quad E < E_{\min} \\ \dfrac{E - E_{\min}}{E_{\max} - E_{\min}} & , \quad E_{\min} < E < E_{\max} \\ 1 & , \quad otherwise \end{cases} \tag{3}$$

where: E_{min} is the minimum energy consumption and E_{max} is the maximum energy consumption needed for finishing the running application.

Because the energy consumption follows the principle "the smaller the better", the energy utility u_e will be defined as $u_e = 1 - u_e'$.

b) Quality Utility - u_q

We define a zone-based quality sigmoid utility function as illustrated in Figure 4. The quality utility is computed based on the predicted average throughput of each network, in order to describe the user satisfaction.

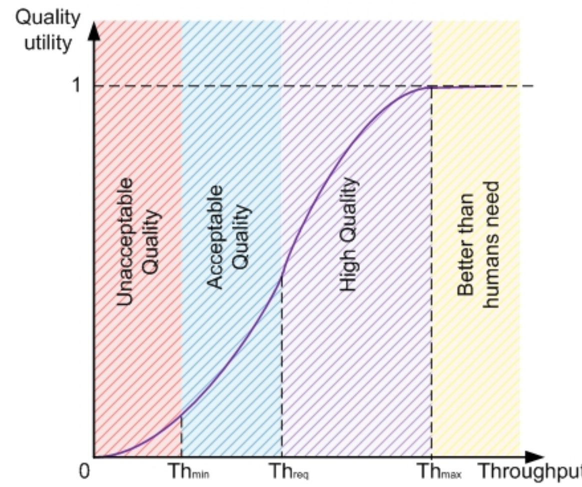

Figure 4. Zone-based quality sigmoid utility function

As we can notice from the figure above, Th_{req} is the essential needed throughput for the application in order to ensure an acceptable good quality. Th_{min} is the minimum required throughput of the application, values below this threshold translating into unacceptable quality levels. Th_{max} is the maximum throughput and values above this threshold link to quality levels which are better than humans need. Values between Th_{req} and Th_{max} link to high quality levels.

The mathematical formulation of the above sigmoid function is given in equation (4).

$$u_q = 1 - e^{\frac{-\alpha * Th^2}{\beta + Th}}. \tag{4}$$

where: α and β are two positive parameters which determine the shape of the utility function and Th is the predicted average throughput for each of the candidate networks.

c) Cost Utility - u_c

Because the monetary cost also follows the principle "the smaller the better", the cost utility u_c is defined as $u_c = 1 - u_c'$ where u_c' is given by equation (5):

$$u_c' = \begin{cases} 0 & , \quad C < C_{\min} \\ \dfrac{C - C_{\min}}{C_{\max} - C_{\min}} & , \quad C_{\min} < C < C_{\max} \\ 1 & , \quad otherwise \end{cases} \tag{5}$$

where: C - is the monetary cost for the current network, C_{min} - minimum cost that the user is willing to pay and C_{max} - maximum possible cost that the user can afford to pay.

d) Mobility Utility - u_m

In terms of user mobility, we define the following categories:

- high speed such as vehicular speed ($>$ 5.3km/h)
- low speed like walking speed ($\leq$ 5.3km/h)
- stationary users – do not require mobility support

Based on the above categories the mobility utility is defined as follows:

$$u_m = \begin{cases} 0 & if \quad high\ speed\ user\ \&\ WLAN \\ 0.5 & if \quad high\ speed\ user\ \&\ WMAN\ /\ Cellular \\ 1 & if \quad otherwise \end{cases} \quad (6)$$

The user mobility has an impact in the utility function only for the case of high speed users. Since a high speed user may be in the coverage area of a short range network only for a few seconds/minutes, there is no need for handover.

D. Information Gathering

As stated before, the parameters considered in the network selection algorithm are: monetary cost, application requirements, estimated average throughput, estimated energy consumption, and user mobility.

Information about network type and monetary cost can be collected through beacon packets transmitted periodically by the APs/BSs. We assume that information about the application requirements such as required data rate, which depends on the application type, can be collected from the application layer. Information about the average throughput or instant PHY rate can be collected at the link layer through the IEEE 802.21 signalling [7].

IV. Numerical Results and Discussions

A. Scenario Description

In this section we describe the simulation scenario and analyze the numerical results. The proposed algorithm is analyzed using a scenario inspired from a typical day in a student's life which walks from home (point A) to school (point E) as illustrated in Figure 5. On his way to school he accesses interactive multimedia and video on demand services through his multi-interface mobile device. He passes through several different network types while watching a video stream on his PDA. The PDA has two wireless interfaces: UMTS and WLAN (802.11b) connecting to the internet through Personal Computer Memory Card International Association (PCMCIA) cards. His mobile device is running low on battery, so the energy efficient network selection algorithm automatically kicks in with higher priority for the energy conservation while keeping high priority for cost. This is as the student does not want to overspend while also desires to finish watching his video. The student is first connected to the UMTS network which has the widest range (point A). As he passes through an area with three available wireless networks: UMTS, WLAN1 and WLAN2, four network selection decisions will be made at the following points: B, C, D and E.

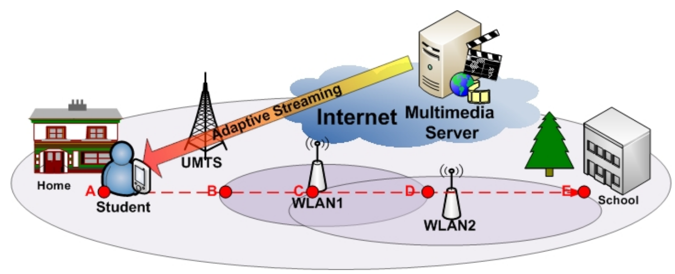

Figure 5. Simulated Scenario

B. Setup Parameters and Assumptions

In the above presented context, the user profile in use for the network selection mechanism includes the following settings: cost, energy, quality and user mobility hence w_c= 0.4, w_e= 0.4, w_q = 0.2, w_m= 0, C_{min} = 0, and C_{max}= 1 respectively. The monetary cost and energy weights have the same value as both are very important to the user (he wants to conserve the lifetime of his mobile device at minimum price). As the user is walking at a constant speed, user mobility will not be considered.

The setup parameters for each of the considered networks are printed in Table I:

TABLE I. Networks Setup Parameters

Network type	Setup Parameters	
UMTS	Cell radius (km)	2
	Monetary Cost (units)	0.9
	Carrier Frequency (GHz)	2
	Transport channel type	DCH
	Downlink bit rate BW (kbps)	384
	Uplink bit rate (kbps)	128
	Downlink TTI (ms)	10
	Uplink TTI (ms)	20
WLAN1	Cell radius (km)	0.1
	Monetary Cost (units)	0.2
	Carrier Frequency (GHz)	2.4
	Bandwidth (kbps)	11000
	Delay (ms)	45
	Jitter (ms)	10
WLAN2	Cell radius (km)	0.
	Monetary Cost (units)	Free
	Carrier Frequency (GHz)	2.4
	Bandwidth (kbps)	11000
	Delay (ms)	65
	Jitter (ms)	20

The user is running a MPEG-4 video streaming with the assumed application requirements listed in Table II.

TABLE II. Application Requirements

Application type	MPEG – 4 (Interactive Multimedia)	
Average Duration	20 min	
Required BER	10^{-4}	
Max delay tolerance	100ms	
Max allowable packet dropping rate	1%	
UMTS requirements	Th_{min}(Kbps)	64
	Th_{req}(Kbps)	128
	Th_{max}(Kbps)	256
WLAN requirements	Th_{min}(Mbps)	0.5
	Th_{req}(Mbps)	1
	$Th_{desired}$(Mbps)	1.5
	Th_{max}(Mbps)	6

The data rate of the video stream can vary in accordance with the wireless network conditions. Because of the constraints of the wireless links, the available throughput for each interface can vary significantly which will determine a variation in energy performance of the interface.

When it comes to energy conservation, a series of factors have to be taken into consideration. The user device type and its characteristics, type of applications running on the device, number and type of wireless interfaces, user location (as it might not be possible to connect to the network using a certain interface), network load and congestion, server load, transmission rate, etc. have a great impact in the energy consumption. In order to simplify the testing environment we assume that the mobile user is running a multimedia streaming application only.. The values used for the energy consumption per unit time of the mobile device (r_t) and the energy consumption rate for data/received stream (r_d) [6] are presented in Table III:

TABLE III. r_t & r_d VALUES FOR EACH INTERFACE

Interface	r_t [W]	r_d [J/Kb]
UMTS	0.86687	0.00154
WLAN1	0.62815	0.000412
WLAN2	0.07827	0.00202

Making use of the data from Tables I, II and III and considering the average throughput obtained by the user in each of the networks, the overall utility is computed as in Table IV:

TABLE IV. NUMERICAL RESULTS

	UMTS	WLAN1	WLAN2
Th_{av}	128kbps	1Mbps	0.5Mbps
E_{av}	1276.78J	1260J	1344.7J
u_e	0.970	0.981	0.980
u_c	0.1	0.8	1
u_q	0.0074	0.28	0.093
U	**0.147**	**0.7035**	**0.616828**

Figure 6 illustrates the simulation steps in which the network decision mechanism is triggered. The simulation starts in point A with the user connected to the UMTS network which is the most expensive but offers the needed service to the client. As the user advances in his path it reaches point B where WLAN1 is detected and the network selection mechanism is triggered. At this point the choice is between UMTS and WLAN1 and the utility results show that WLAN1 is selected as target network as it offers higher throughput which leads to a better quality, has lower power consumption and costs less. As the user reaches point C, the decision will be made between three networks: UMTS, WLAN1 and WLAN2. Although WLAN2 is a free hotspot, the decision is to remain connected to WLAN1 because in comparison to WLAN2, WLAN1 offers higher bandwidth and less energy consumption. In point D, the user goes out of the coverage area of WLAN1 so the decision mechanism selects WLAN2 as target network in contrast to UMTS. In point E the user reaches the destination.

V. Conclusions and Future Work

This paper proposes an energy-aware utility function for user-centric network selection strategy and multimedia delivery in a heterogeneous wireless environment. Based on the mobile device type, application requirements, network conditions and user preferences, the proposed function selects the best value network which satisfies the user needs.

Test results have showed that the proposed utility function achieves a good trade-off between energy consumption, monetary cost and network load, acting in the user's best interest.

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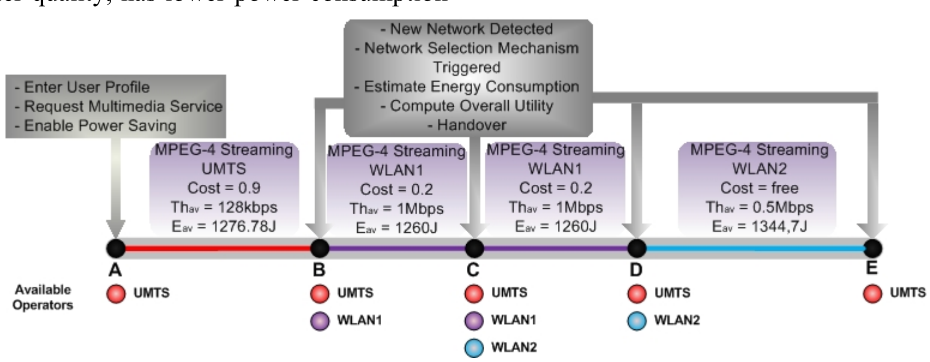

Figure 6. Simulation Steps